

## PERSPECTIVES IN ESTUARINE AND COASTAL SCIENCE

# Recommendations on Establishing a Research Strategy in the Gulf of Mexico to Assess the Effects of Hurricanes on Coastal Ecosystems

STEPHEN A. BORTONE\*

*Marine Laboratory, Sanibel-Captiva Conservation Foundation, 900A Tarpon Bay Road, Sanibel, Florida 33957*

**ABSTRACT:** Scientists along the Gulf of Mexico and southeastern United States inevitably are asked to investigate the environmental effects of such extreme natural events as hurricanes. Since the usual post-event sampling strategy is often based upon the application of a pre-event study design that was not originally intended to evaluate disturbance effects, a hurricane evaluation strategy is needed that establishes sampling coverage through a broad network. Coupling this evaluation strategy with the refinement of several estuarine indicators to assess environmental change will facilitate the evaluation of hurricane effects. Establishing the sampling network and concomitant protocols requires cooperation among scientists and agencies. Fortunately, the number and location of existing laboratories and investigations into establishing estuarine indicators is at hand. Developing a sampling network and protocols will better enable scientists to evaluate the effects of short-term, focused, and intense environmental disruptions.

### Introduction

Hurricanes have largely been treated by the scientific community (and supporting agencies) as rare, unpredictable, and short-lived phenomena (e.g., Bries et al. 2004). The premise behind most environmental science is that ecosystem responses to disturbances are both deterministic and predictable. While our approach to investigating the ecological effects of hurricanes has attempted to operate under this same premise, the fundamental attribute of applying good science has been lacking. This lack of adherence to the fundamentals has been tolerated, principally because of the independent organizational positions maintained by both scientists and their research institutions and the lack of appreciation for the scale at which hurricanes influence the environment (Donnelly et al. 2001; Edmunds 2002).

Below is an examination of the flaws associated with our past efforts and how they have impeded a more rational approach towards satisfying both the deterministic and predictable attributes of scientific inquiry. An operational approach toward resolving the current situation in hurricane-re-

sponse research is also offered. Included in the outline for this approach are some instructions to help establish an initial plan from which more fully refined, consensus-based operational plans for sampling protocols can be developed. Consideration is also given to resolving issues associated with implementing large-scale, multi-jurisdictional, long-term assessments of hurricane effects on coastal ecosystems, particularly those associated with the Gulf of Mexico.

### Background and Justification

Most research on hurricanes is conducted in response to hurricanes as abnormal, but extreme, environmental events. The literature is rife with examples of limited time and place comparisons. Some of these are before-and-after efforts to assess the effects of hurricanes on single (Bortone 1976) or multiple (Fenner 1991) community attributes. Many assessments are snap shots representing a presumed observed change with only inferred or limited reference to previous conditions (e.g., Bortone 1976), while other studies include long-term investigations evaluating the recovery from the hurricane's disturbance (Livingston et al. 1999; Turpin and Bortone 2002; Litaker and Tester 2003).

At best, the response of the scientific community to hurricane effects has been, and continues to be, largely opportunistic. Much of the research was

\* Corresponding author; current address: Minnesota Sea Grant College Program, University of Minnesota, 2305 East Fifth Street, Washburn Hall, Duluth, Minnesota 55812; tele: 218/726-8107; fax: 218/726-6556; e-mail: sbortone@umn.edu

predicated on the serendipitous circumstance of researchers having collected some environmental data in the general area at some pre-disturbance time. These data were most often collected without regard to the possibility of their being used to test or evaluate the effects of hurricanes. The explanation for our historical action is presumably based upon the premise that hurricanes, and other natural extreme events, are largely unpredictable. The time that might occur between events can be considerable, and storms of similar characteristics with regard to intensity, duration, and direction are unlikely to be repeated within any reasonable time. The practical pressures on researchers with regard to promotion, tenure, and grantsmanship, may preclude serious, concentrated efforts into the investigation of hurricanes.

The significance of these circumstances cannot be overstated, especially in light of the probability that hurricanes have significant and long-term influences on shaping our coastal environment, in terms of both physical and biological community structure (Frederick et al. 1994; Paerl et al. 2001). Investigations into the changes that occur within estuaries and along coastal areas at various spatial and temporal scales are recognized as paramount to our understanding of these ecosystems (Adams and Bortone 2005).

The argument that hurricanes are unpredictable in both time and space, although understandable, is influenced by a lack of appreciation for the frequency at which hurricanes occur. Examination of hurricane tracks in the Gulf of Mexico over the last 100 years (<http://www.csi.lsu.edu/cml2/research/louisiana/surge1/gulfh.jpg>) strongly suggests that virtually every part of the Gulf's coastline has been repeatedly affected by hurricane force winds and surge. These storms have had a major effect on shaping the Gulf environment, yet the vast majority of scientific studies in the region have focused on the regular and repeated assessment of factors in these same areas during nonstorm periods. Hurricanes may indeed be large, but on a scale significant to the restructuring of geological features and biological communities, they are not infrequent (Donnelly et al. 2001).

A solution to the situation is long overdue but attainable. Figure 1 depicts the approximate placement and number of research laboratories (Federal, state, local, academic, and private) that conduct investigations along the Gulf of Mexico, northern Caribbean Sea, and south Atlantic coasts of the United States. The number and location of these research facilities offer the potential for facilitating the development of a large-scale, long-term sampling network that could begin to amass data appropriate to the scientific assessment of the

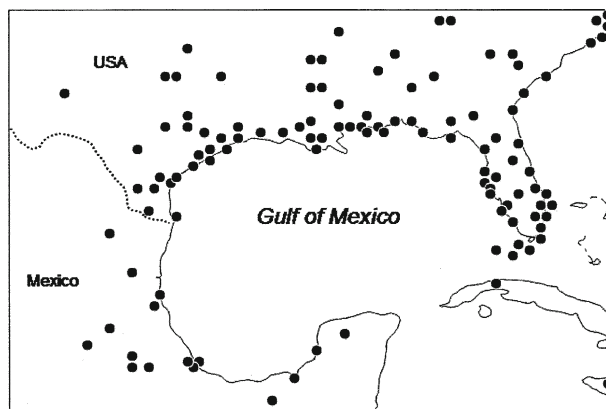


Fig. 1. Distribution and abundance of research laboratories in the coastal areas of the Gulf of Mexico. Figure modified from a map provided by GulfBase ([www.gulfbase.org](http://www.gulfbase.org)), a project of the Harte Research Institute for Gulf of Mexico Studies at Texas A&M University, with additions from the Southern Association of Marine Laboratories (SAML) and the Organization of Biological Field Stations (OBFS).

effects of hurricanes on meaningful spatial and temporal scales.

Below is an outline for establishing the sampling network. This outline should not be considered as complete, but rather it should serve as basis from which the scientific community can develop a more cohesive hurricane assessment plan.

### Procedure for Establishing a Sampling Network and Protocols

#### IDENTIFICATION OF PARTICIPANTS

The number of research facilities involved in establishing the network is largely dependent on the ability of the facilities and scientists to meet some basic criteria. Geographic distribution is, perhaps, a priority in the establishment of a hurricane sampling network. Early, timely, and frequent access to sampling locations, both within and proximate to the region of the storm event is paramount. While proximity to sampling sites is a luxury in most sampling efforts, it is a necessity for hurricane studies. Recent storms along the northern Gulf of Mexico have indicated that these storms often limit access both to and within hurricane affected areas. Selection criteria for potential participants should be based on accessibility to affected areas. Research efforts should be conducted minimally every 100 km along the coast to facilitate both pre-hurricane and post-hurricane sampling efforts. Along the northern Gulf of Mexico and Florida's southeast coast, this condition could be easily met given the number and location of existing research facilities.

Scientific expertise and experience among the researchers at the indicated facilities are certainly important criteria. Understandably, many institutions do not have the expertise and experience in every discipline of interest, but a high level of familiarity is desirable. In areas where there are more than a few facilities within or near postulated zones of effect, a shared responsibility (commensurate with abilities) should be undertaken.

An additional attribute is the historical activity participants have had in responding to the examination of hurricane effects in coastal areas. Some organizations have considerably more experience and historical interest in continuing and expanding their efforts on hurricane assessment than others.

#### IDENTIFICATION OF METHODS AND ESTABLISHING SAMPLING PROTOCOLS

In the proposed large-scale, multi-jurisdictional sampling network, an important task will be to establish an integrated, multi-relational database of environmental information that will serve the needs of a broad range of individuals. To construct such a database, each participating organization needs to adopt compatible and comparable sampling protocols among a pre-selected minimum of essential environmental variables. The establishment of a database of environmental data collected both pre-storm and post-storm, in a consistent and comparable manner, is paramount to achieving the overall goal of better understanding hurricane effects.

Variable selection and establishing the specific sampling protocols to be applied are daunting but surmountable given that some effort has already been directed toward this goal in estuarine ecosystems (Bortone 2005). Scientists representing each subdiscipline should convene to establish the variables to be sampled and their concomitant protocols. While consensus among scientists will be difficult, establishing a set of variables to be sampled under standardized protocols is achievable with the realization that the number of variables is limited, and methodological consensus need only occur on some basic sampling techniques.

Variable-selection criteria should be based on historical importance and environmental significance as well as on anticipated relevance. Simultaneous with the convention of scientists identifying sampling variables and methodology, an inventory should be conducted to identify large-scale, long-term databases that have relevance to hurricane-effect investigations. Variable selection will be partially based on the utility of historical comparison. The examination of historical databases has an added benefit of serving to identify needs and gaps in the historical database as well as identifying

variables that have much to offer in future investigations of hurricane effects.

#### METHOD EVALUATION

Prior to the adoption and implementation of sampling protocols for identified sampling variables, an examination of the existing historical data should occur because much can be learned by conducting a full examination of these data with regard to establishing a large-scale sampling network. This examination should be congruent with the effort mentioned above that examines the historical application of methods. Here, consideration should be given to the results of those efforts. The practicality of such an inspection becomes apparent when decisions are finally made as to the applicability of techniques to quantify specified variables. This inspection process will allow further refinement of methods and pare the list of variables to be examined.

Once the final list of variables and sampling protocols has been determined, the protocols should be tested for applicability. It will not be possible to fully test the sampling protocols under real conditions, but simulation testing is possible and practicable. Modeling hurricane effects has already been conducted on several environmental attributes (Gaus et al. 1984; Peng et al. 2003). This step will allow emendations to the sampling protocols. It should be noted that subsequent to actual implementation of the sampling protocols during hurricane conditions, emendations will likely take place upon conferral with study participants.

#### DATA ARCHIVING

Equally as important as establishing sampling protocols is the adoption of a common, easily accessible database. The database should include attributes that allow for consistent data formatting and quality-control inspection to ensure data utility. The data will likely be stored independently at each participant site as well as at a single, accessible headquarters.

#### DATA ANALYSES

A general framework for data analyses is analogous to a previous effort of establishing data analyses protocols for artificial reef studies (Portier et al. 2000). The placement of an artificial reef has the assessment requirements for monitoring an environmental disturbance that is similar to hurricanes, but clearly on a different scale. Analyzing environmental data can be conducted on at least three levels based on complexity of the questions being asked and the quality of data with regard to frequency, intensity, and duration of sampling

(Seaman and Jensen 2000). Descriptive analyses can provide measures of central tendency of the variables evaluated. Descriptive analyses allow for status determinations but generally only have utility in serving as a snap shot of conditions and circumstances. Comparative analyses are essentially conducted on time-based and location-based sampling events (time series: paired or repeated before-and-after; location: two or more sites). Much of the data presented in this volume follows this analytical format. Interrelational analyses make use of factor analyses to allow determination of variable interactions. The advantage of conducting research studies that allow legitimate use of interrelational analyses is that cause can be inferred and hypotheses tested. All three analytical approaches also allow for hypotheses generation.

A long-term goal for establishing the hurricane sampling network and protocol outlined here is to eventually obtain data that allow for interrelational analyses. Simultaneous with each of the three analytical frameworks offered above is the development of models that are predictive, comparative, and interrelational at the same time.

#### POST-ANALYSIS DISSEMINATION

Key to the success of the hurricane-assessment network is the timely dissemination of the information obtained as a result of the effort. Posting the data and analytical results on a readily accessible website will be significant in furthering the goal of hurricane assessments. The difficulty lies in the strict quality control that must be maintained on data loaded onto the site. Another anticipated impediment to achieving network success is the change in attitudes that must concomitantly occur among the participating researchers. Historically, scientists have been reluctant to offer their data until published. For the program to succeed there must be an attitude shift in the ownership of data.

Data ownership could easily succumb to data being perceived as *res communes*. Given the international or national distributional nature of the database, and the continuum of data to be included, it is paramount that an avenue be created and diligently maintained that allows for full access to all the data gathered as part of this program. Given the enormity of the task approaching an understanding of hurricane effects, anything short of full access to all data undermines the underlying principle of the network.

To encourage full participation by the scientific community, regular formal publications and presentations of results will be required for participation. This participation ensures recognition of the contributions of participants and also facilitates the timely distribution of the study results. Regular

workshops should also be scheduled. These public forums allow for rapid data dissemination and a degree of responsibility and authority ascribed to the studies.

The views above will probably be met with a degree of skepticism among colleagues who may be uncomfortable with data dissemination prior to publication. There are existing programs that currently operate successfully under this guiding principle; most notably is Florida Bay and Adjacent Marine Systems Science Program, which is a science component of the South Florida Ecosystem Restoration initiative ([www.aoml.noaa.gov/flbay/](http://www.aoml.noaa.gov/flbay/)).

#### ORGANIZATION

Paramount to the program's success is the organizational framework of initiating and maintaining the network. Already indicated are some initial organizational efforts designed to bring a team approach to data-gathering protocols. Once these protocols have been determined, a schedule must be established and followed. Annual conventions need to be included that allow for discussion of results with considerations given to amending the sampling protocols. This annual procedure for modification is essential to fine tune the program but also to respond to the problems incurred.

Another organizational feature that must be considered is the overall management responsibility. There are several ways in which this can occur (i.e., hierarchical, rotational, democratic, parallel, etc.). Umbrella groups within states or regions may be able to assume some of this additional responsibility. National leadership, although not essential, is likely to assume the largest portion of the organizational effort. National leadership is logical because several of these agencies already assume some roles in multidisciplinary approaches toward resolving environmental issues. The U.S. Environmental Protection Agency's National Coastal Assessment helped establish a comprehensive integrative monitoring program to assess coastal resources. Environmental Monitoring and Assessment Program (EMAP) and its partners have begun this assessment in estuarine and coastal areas to be able to answer broad-scale questions on environmental conditions. The Gulf of Mexico Program (GMP) developed the Joint Gulf States Monitoring Plan (JGSMP) that forms linkages with natural resource agencies to act synergistically with EMAP. The U.S. Geological Survey plays an essential role in the endangered species programs, National Oceanographic and Atmospheric Agency/National Marine Fisheries Service (NOAA/NMFS) has ecosystem level programs directed toward resolving essential habitat issues, and the Minerals Management Service has long been involved in large-scale,



expanded, temporal investigations of land use and environment interactions offshore. Independently at the national level, organizations such as the National Association of Marine Laboratories (NAML), or its subdivision the Southern Association of Marine Laboratories (SAML), may find it appropriate to take the lead in providing organization to the hurricane assessment network. The U.S. Integrated Ocean Observing System through its Southeast Atlantic Coastal Ocean Observing System in conjunction with the University of South Florida's Coastal Ocean Monitoring and Prediction System (COMPS) is an example of a collaborative university partnership that collects and distributes regional oceanic observations. The recently developed U.S. Ocean Action Plan includes a recommendation for a National Coastal Monitoring Network. These programs, both separately and together, are indications of the levels of organizational structure needed to rectify the current situation regarding the lack of long-term assessment of hurricane effects.

Coincident with establishing the organizational framework, strong consideration needs to be given to establishing consistent and predictable funding sources to implement the program. Each research participant's home agency may be equipped to assume some, if not all, of the tasks assigned to that particular organization. This is so because much of the assessment may already be occurring as part of ongoing programs.

### Conclusions

Given the inevitability of hurricanes on our coastal areas, the establishment of a broad-based, comprehensive plan to objectively assess the environmental effects of hurricanes on coastal ecosystems is long overdue. Identification of the potential network of institutions, participants, and organizations is an initial step towards its establishment. Refinement and testing of specific protocols for a limited number of important variables is the second step. The final step is the actual implementation of such a program. I hope that this presentation serves to stimulate the scientific community to achieve these important objectives and provide the foundation for developing a better understanding of the role that hurricanes have in shaping coastal ecosystems.

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### LITERATURE CITED

- ADAMS, S. M. AND S. A. BORTONE. 2005. Future directions for estuarine indicator research, p. 503–506. *In* S. A. Bortone (ed.), *Estuarine Indicators*. CRC Press, Inc., Boca Raton, Florida.
- BORTONE, S. A. 1976. The effects of a hurricane on the fish fauna at Destin, Florida. *Florida Scientist* 39:245–248.
- BORTONE, S. A. 2005. *Estuarine Indicators*. CRC Press, Inc., Boca Raton, Florida.
- BRIES, J. M., A. O. DEBROT, AND D. L. MEYER. 2004. Damage to the leeward reefs of Curacao and Bonaire, Netherlands Antilles from a rare storm event: Hurricane Lenny, November 1999. *Coral Reefs* 23:297–307.
- DONNELLY, J. P., S. S. BRYANT, J. BUTLER, J. DOWLING, L. FAN, N. NAUSMANN, P. NEWBY, B. SHUMAN, J. STERN, K. WESTOVER, AND T. WEBB III. 2001. 700 yr. sedimentary record of intense hurricane landfalls in southern New England. *GSA Bulletin* 113:714–727.
- EDMUNDS, P. I. 2002. Long-term dynamics of coral reefs in St. John, U.S. Virgin Islands. *Coral Reefs* 21:357–367.
- FENNER, D. P. 1991. Effects of Hurricane Gilbert on coral reefs, fishes and sponges at Cozumel Mexico. *Bulletin of Marine Science* 48:719–730.
- FREDERICK, B. C., S. GELSANLITER, J. A. RISI, AND H. R. WANLESS. 1994. Historical evolution of the southwest Florida coastline and its effect on adjacent marine environments. *Bulletin of Marine Science* 54:1074–1075.
- GAUS, R. R., I. G. MACINTYRE, AND B. E. HERCHENRODER. 1984. Computer simulation of the reef zonation at Discovery Bay, Jamaica: Hurricane disruption and long-term physical oceanographic controls. *Coral Reefs* 3:59–68.
- LITAKER, R. W. AND P. A. TESTER. 2003. Extreme events and ecological forecasting, p. 85–91. *In* N. Valette-Silver and D. Scavia (eds.), *Ecological Forecasting: New Tools for Coastal and Marine Ecosystem Management*. National Oceanic and Atmospheric Administration Technical Memorandum NOS-NCCOS-1. Washington, D.C.
- LIVINGSTON, R. J., R. L. HOWELL IV, X. NIU, F. G. LEWIS III, AND G. C. WOODSUM. 1999. Recovery of oyster reefs (*Crassostrea virginica*) in a Gulf estuary following disturbance by two hurricanes. *Bulletin of Marine Science* 64:465–483.
- PAERL, H. W., J. D. BALES, L. W. AUSLEY, C. P. BUZZELLI, L. B. CROWDER, L. A. EBY, J. M. FEAR, M. GO, B. L. PEIERLS, T. L. RICHARDSON, AND J. S. RAMUS. 2001. Ecosystem impacts of three sequential hurricanes (Dennis, Floyd, and Irene) on the United States' largest lagoonal estuary, Pamlico Sound, NC. *Proceedings of the National Academy of Sciences of the United States* 98:5655–5660.
- PENG, M., L. XIE, AND L. J. PIETRAFESA. 2003. A numerical study of storm surge and inundation in the Croatan-Albemarle-Pamlico Estuary system. *Estuarine Coastal and Shelf Science* 59:121–137.
- PORTIER, K. M., G. FABI, AND P. H. DARIUS. 2000. Study design and data analysis issues, p. 21–50. *In* W. Seaman Jr. (ed.), *Artificial Reef Evaluation—With Application to Natural Marine Habitats*. CRC Press, Inc., Boca Raton, Florida.
- SEAMAN, JR., W. AND A. C. JENSEN. 2000. Purposes and practices of artificial reef evaluation, p. 2–19. *In* W. Seaman Jr. (ed.), *Artificial Reef Evaluation—With Application to Natural Marine Habitats*. CRC Press, Inc., Boca Raton, Florida.
- TURPIN, R. K. AND S. A. BORTONE. 2002. Pre- and post-hurricane assessment of artificial reefs: Evidence for potential use as refugia in a fishery management strategy. *ICES Journal of Marine Science* 59:S74–S82.

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